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Comparison between Near Infrared Spectroscopy and Hyperspectral Imaging in Predicting Beef Eating Quality

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I. Introduction

Consumer perception of beef quality has been shown to be largely dependent upon three factors, which are tenderness, juiciness and flavour. Usually, objective evaluation of tenderness can be achieved by measuring the mechanical properties of the beef sample using slice shear force (SSF). The other two factors, juiciness and flavour are assessed by a sensory taste panel. Ultimate pH has a relationship to both juiciness and tenderness. However, both shear force tests and pH tests are unfeasible for fast-paced industry on-line use because they are costly, time-consuming and destructive [1]. Thus, the aim of the present experiment was to develop an efficient approach to quantify shear force and pH as indicators of beef eating quality.

Over the past a few decades, some objective approaches for determining meat quality parameters have been developed. Some examples include ultrasound, multispectral imaging, hyperspectral imaging (HSI), near infrared (NIR) spectroscopy and various computer vision techniques. Among these approaches, NIR spectroscopy is the most widely used technique for meat quality evaluation due to its rapidity and simplicity. One major drawback of the method is its low spatial resolution for analysing non-homogeneous composition of meat samples [2]. To this end, HSI integrating both spatial and spectral information has emerged. In recent years, several researchers have demonstrated that the HSI technique has some promise for the prediction of beef quality parameters [3]. But to our knowledge, there is no research comparing these two techniques on the same dataset, so little is known about whether HSI outperforms NIR spectroscopy.

The objective of the paper was to compare the prediction accuracy of beef eating quality parameters, including slice shear force (SSF) and ultimate pH, using datasets acquired by NIR spectroscopy and HSI system. The support vector machine (SVM) was employed to construct calibration equations.

II. Materials and Methods

A. Beef Sample Preparation and Spectral Information Collection

A total of 858 cattle were collected in 4 commercial abattoirs across Scotland. In each abattoir, over 200 beef samples were randomly selected in the production line. Allowing for 48 hours of aging, a 25 mm piece of steak sample containing the M. longissimus thoracis was removed from each carcass. After blooming for 2 minutes [4], HSI samples were collected using an HSI system (Gilden photonics) with wavelength ranging from 283.23 nm to 862.90 nm, followed by an NIR spectrometer (ASD Labspec Pro) with wavelength from 350 nm to 2500 nm. The NIR spectrometer is fitted with an internally-illuminated fibre optic probe with a 68 mm Ø active scanning area. Due to the fact that only a small area can be collected by the NIR spectrometer at a time, scans were replicated in 10 random places for each steak to capture the maximum variation across the sample.

B. Meat Quality Measurements

Each steak was divided into 2 halves after imaging, labelled and vacuum packaged. One half was aged for an additional 5 days at -1℃ and the other half was aged for an additional 12 days under commercial conditions. Thus, steak samples were aged for 7 days and 14 days in total. Before quality measurements, samples were defrosted at ambient temperature for 24 hours. Ultimate pH was determined with a calibrated Hanna meat pH meter (HI 99163), followed by the tenderness measurement. Steaks were cooked on a clam-shell grill until the internal temperature reached 71℃. Once cooked, a slice of steak was sheared orthogonal to the muscle fibre axis using a Tenderscot tenderometer. The peak force was extracted as SSF during the shear process. Therefore, there are 4 beef quality parameters in total for each steak, which are pH7, pH14, SSF7 and SSF14.

C. Data Processing

For HSI and NIR spectra, excessive noises can be noticed in the extreme of both spectral ranges. After removing noises, the working wavelengths for NIR spectra and HSI spectra are 501 nm – 2200 nm and 490.42 nm – 862.90 nm respectively.

The lean part of the steak was discriminated from the fat part through thresholding using reflectance values in HSIs. In order to save time, a small area was selected from the lean part and then the average reflectance spectrum was achieved. After that, both reflectance spectra from NIR and HSI were converted to absorbance (1/R) by logarithm transformation to linearize the relationship between the concentration of an absorbing compound and the absorption spectrum [5].

It is well known that SVM is sensitive to the curse of dimensionality [6]. Therefore, principal component analysis (PCA) was applied to the whole dataset to extract features and reduce dimensionality. Steak samples were then split into 2 datasets, where 75% was used for calibration and 25% was used for validation. A 4-fold cross-validation was adopted to optimise parameters for the calibration set to avoid over-fitting.

III. Results and Discussion

Prediction results of NIR spectra and HSI for both calibration dataset and validation dataset are shown in Table 1 and Table 2 respectively. Comparing values of coefficient of determination (R^2) in Table 1 and Table 2, for most of those parameters, HSI gives a better prediction performance than NIR spectroscopy. Even though for SSF14, NIR spectroscopy yields a higher R^2 than HSI slightly, its ratio of the performance deviation (RPD) is still lower than that of HSI.

One thing worth of noting is that the HSI system used in the experiment is in visible range, which means that the prediction results might be even higher if a VSI-NIR HSI system is applied. In addition, future work needs to be done to extract texture features from HSI data, which will be combined with spectral features together to improve the prediction model further.

IV. Conclusion

This paper compares the ability of NIR spectroscopy (501 nm – 2200 nm) and HSI (490.42 nm - 862.90 nm) for predicting beef eating quality, including SSF and pH at 7 days and 14 days post mortem. Considering the high dimensionality of those datasets, PCA was used to reduce data dimensions and SVM was applied to construct prediction models. This research suggests that compared with NIR spectroscopy, HSI may offer more additional information that could help to improve prediction of beef quality attributes, with an improvement in both R^2 and RPD.

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Table 1. Performance for predicting all abattoirs instrumental meat quality in beef M. longissimus thoracis using NIR spectroscopy and HSI in the calibration dataset, with noise removed spectra.

Trait	NIR spectroscopy for data modelling				HSI for data modelling			
	n	PC[a]	R^2_{cal} (%)	$RMSE_{cal}$[b]	n	PC[a]	R^2_{cal} (%)	$RMSE_{cal}$[b]
SSF7	644	25	34.7	39.14	644	45	38.6	37.80
SSF14	644	25	47.0	34.91	644	50	58.5	30.61
PH7	644	20	58.9	0.07	644	40	73.8	0.18
PH14	644	5	41.7	0.09	644	45	69.6	0.06

Table 2. Performance for predicting all abattoirs instrumental meat quality in beef M. longissimus thoracis using NIR spectroscopy and HSI in the validation dataset, with noise removed spectra.

Trait	NIR spectroscopy for data prediction					HSI for data prediction				
	n	PC[a]	R^2_{val} (%)	SE_{val}[c]	RPD_{val}[d]	n	PC[a]	R^2_{val} (%)	SE_{val}[c]	RPD_{val}[d]
SSF7	214	25	9.7	43.86	1.04	214	45	11.2	43.37	1.05
SSF14	214	25	19.1	39.76	1.09	214	50	18.0	39.56	1.10
PH7	214	20	35.1	0.08	1.25	214	40	43.2	0.08	1.25
PH14	214	5	35.5	0.09	1.22	214	45	44.0	0.08	1.38

[a] Number of principal components used for SVM regression; [b] Root mean squared error of calibration set; [c] Standard error of validation set; [d] Ratio of performance deviation (ration between standard deviation of the reference data to the SE_{val}).